Autonomous Mesoscale Vehicles: Mobility and Cooperative Behavior

Barry Spletzer, Sandia National Laboratories

This presentation will describe the recent work by the Intelligent Systems and Robotics Center at Sandia National Labs to produce autonomous cooperating mesoscale vehicles. The two main areas covered will be the use of hopping as a means to provide exceptional mobility for small-scale vehicle and the development of cooperative behavior among swarms of autonomous vehicles. The development of the Enhanced Mesoscale Mobility Actuator (the hopper) will be discussed including its terrestrial capabilities and the potential for adapting it to other environments.

Point designs and scaling laws for mobility via hopping will be presented. Recent developments in source localization and perimeter defense will be presented to show the current status of Sandia's work in cooperative distributed behavior.

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Engineered Collectives

(Smaller, Smarter, and More of Them)

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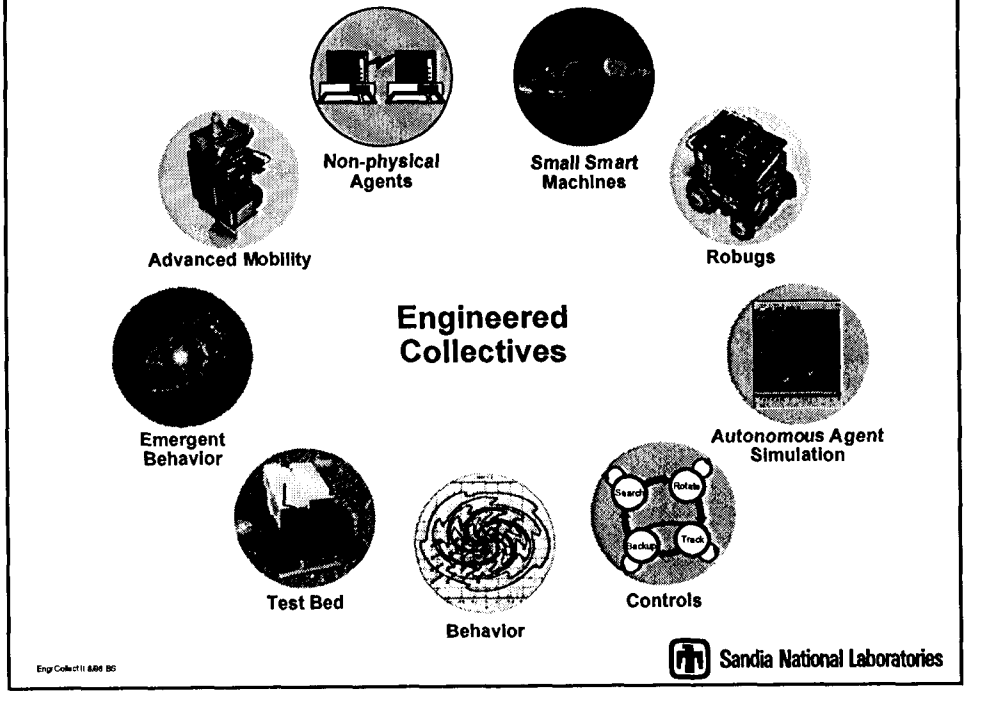
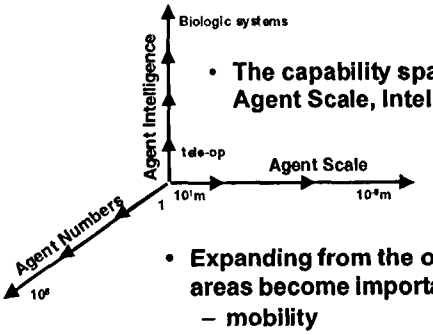


Attributes of Collectives

- Fault tolerant
- Redundant
- Cheap and disposable
- Distributed
- Enhanced capabilities

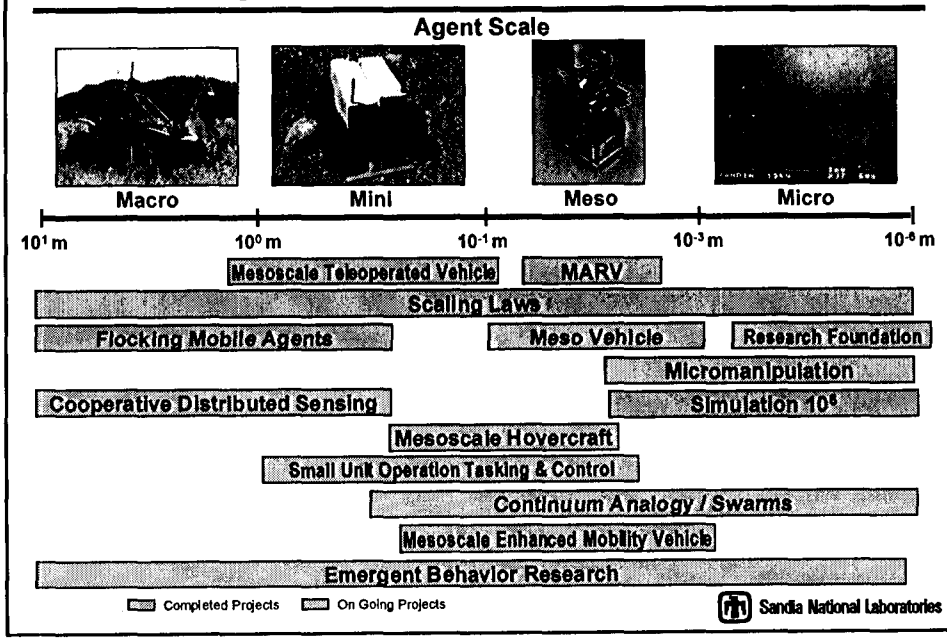
Capabilities of Engineered Collectives



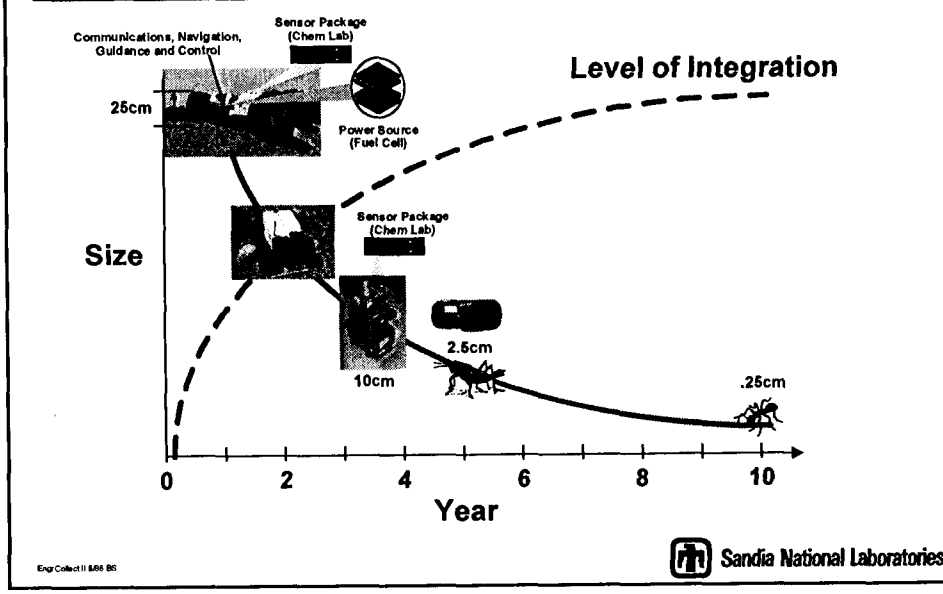
- The capability space is bounded by 3 axes: Agent Scale, Intelligence and Numbers

- Expanding from the origin, these technology areas become important:
  - mobility
  - communications
  - navigation
  - behavior/cooperation
  - sensor systems
  - power supply
- Greater numbers require more intelligence
- Smaller size magnifies single agent issues
- Greater intelligence requires more power

Engineered Collectives Programs

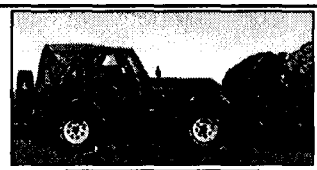


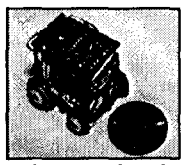
Agent Scale Progression



Mobility and Power in Small Scale

More difficult





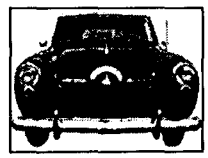
50% Power Supply

Takes more power

5% Power Supply

5000 X Length

Range is limited



150,000 X Length

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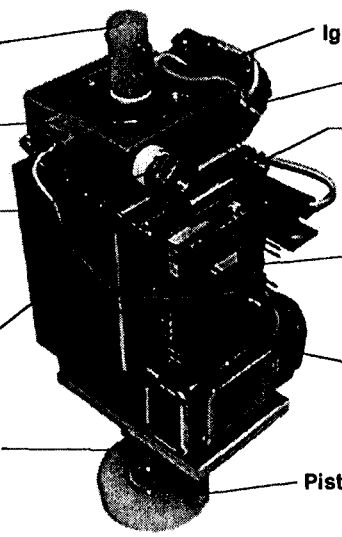
Enhanced Mobility Mesoscale Actuator (EMMA) ...



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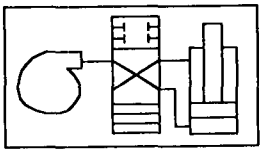
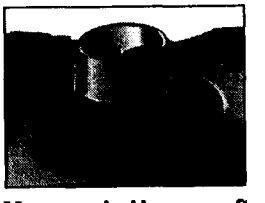
Enhanced Mobility Mesoscale Vehicle

- 200 gm payload
- 1 mg fuel per hop
- 1m single hop range
- 20 km on 10% fuel mass (terrestrial)
- On board oxidizer reduces range by 0.2 g_c/g

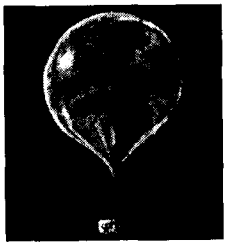
. . . and Beyond



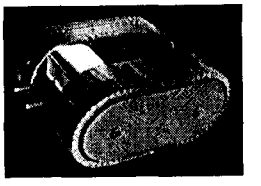
Microscale Hydraulics



Mesoscale Hovercraft

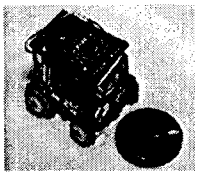


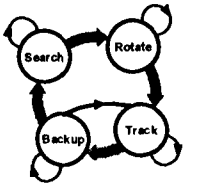
Minimum size Aerostat



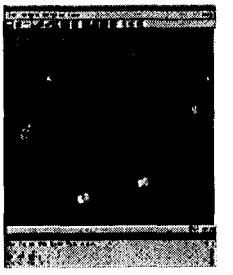
Micro crawler

Controls & Behavior of Engineered Collectives

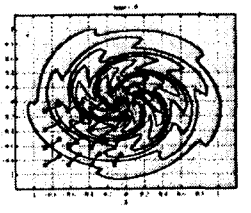




Emergent behavior is surprisingly common



Swarm behavior is complex



Payoff is large

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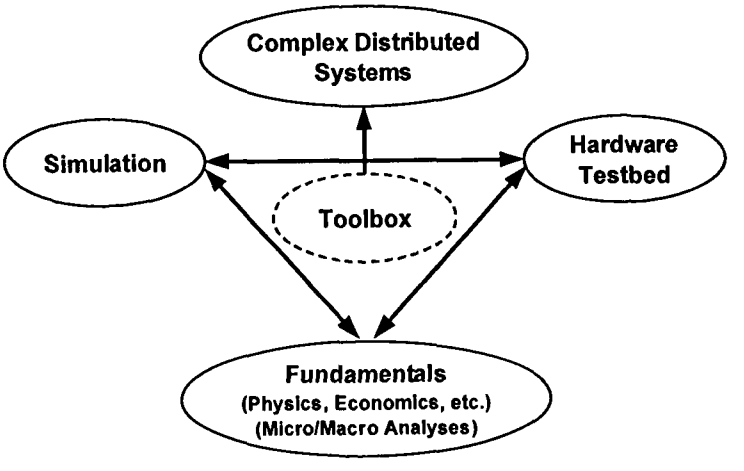
Predicting Emergent Behavior



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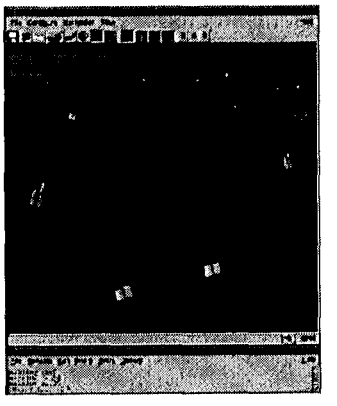
Robotic All Terrain Lunar Exploration Rover (RATLER)

- Originally developed by Sandia as a prototype vehicle for a lunar mission.
- 1'x2'x2' custom composite body and wheels
- Intel 486sxlc, 66MHz, PC-104 form factor, embedded PC
- Differential GPS receiver
- Spread spectrum two-way packet radios communicate to other vehicles and base station (1km range typical)
- Electronic compass and tilt sensors
- Video camera and RF video transmitter
- RF receiver for MIDS sensors

Complex Behavior Requires Simulation

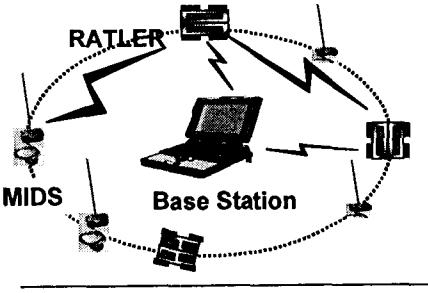


- Provide a virtual environment to study and develop cooperative behavior
- Variable resolution
- Highly modular
- For large numbers
- Hardware verified

Why Simulate?

- Swarm behavior is complex
- Plume behavior is complex
- Control/behavior algorithms do not exist
- The behavior-to-controls relationship is vague
- Real agents are expensive, virtual ones are cheap

Sandia's Robotic Perimeter Detection System



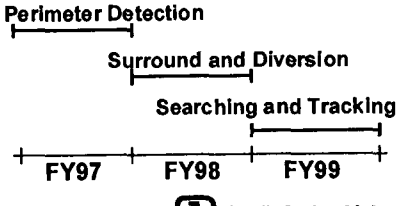
New Ideas

- Decentralized cooperative controls guide multiple robots without human intervention.
- Base station is only used to initialize and abort high level task commands.
- Fault tolerant.
- Provable task convergence.
- Probability of task completion.

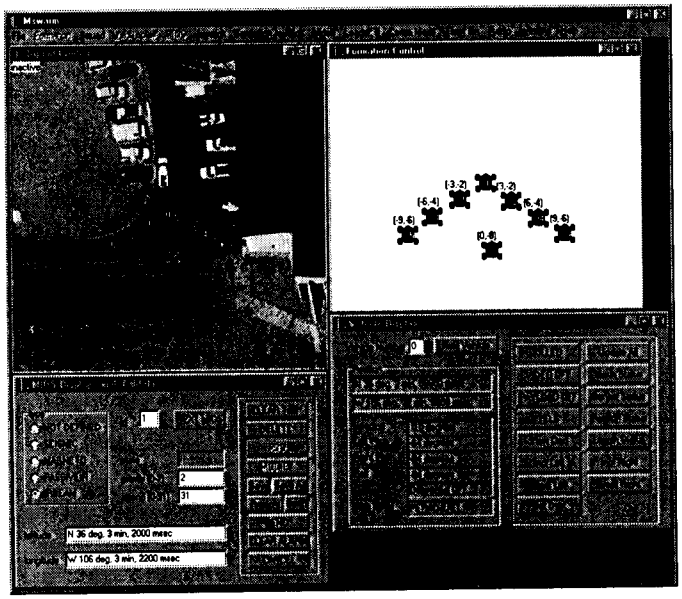
Impact

- Reduce warfighter workload.
- Reduce warfighter danger.
- Improve effectiveness of a single warfighter.
- Improve mobility for redeployment.

Schedule



Base Station Operator Interface: Driving Multiple Vehicles In Formation



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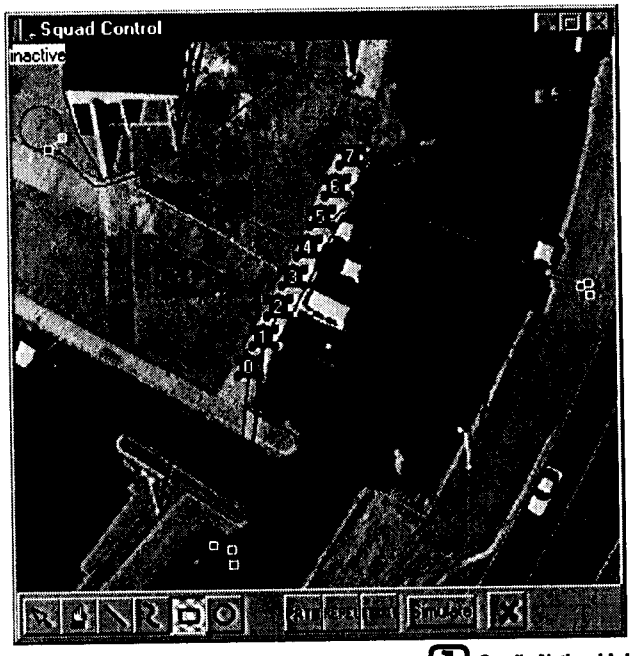
Potential Field Path Planner: Three Goals



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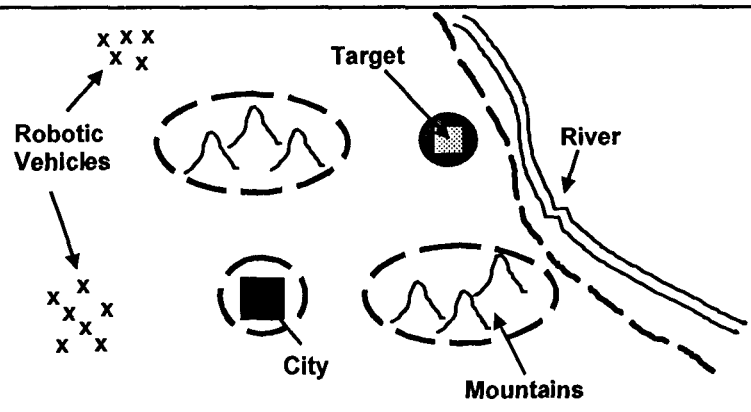
Surround and Diversion Problem



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Controls and Behavior Approaches

- Genetic programming
- Alpha-beta agents
- Inverse plume modeling
- Classical controls approach

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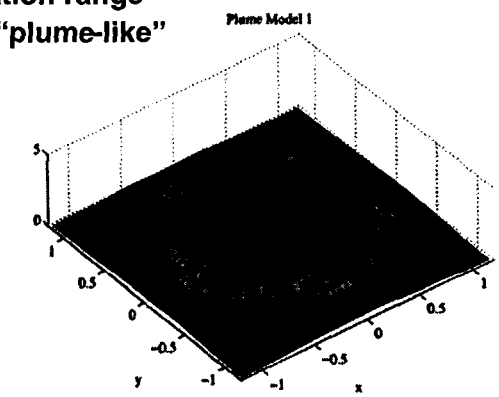
Classical Approach

- Source localization is the goal
- Agents cooperate/share information
- Limited communication range
- Tests with difficult "plume-like" models



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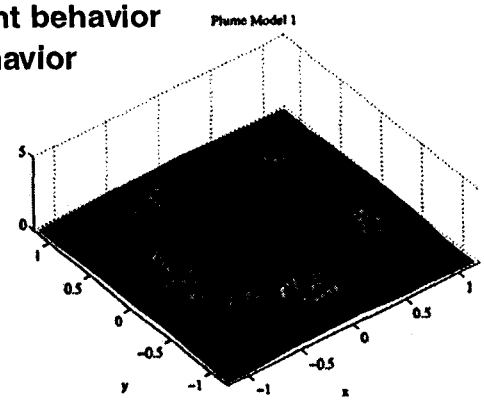
Plume Behavior 1

- Noisy origin
- Pulsating source
- Time dependent behavior
- Plume-like behavior



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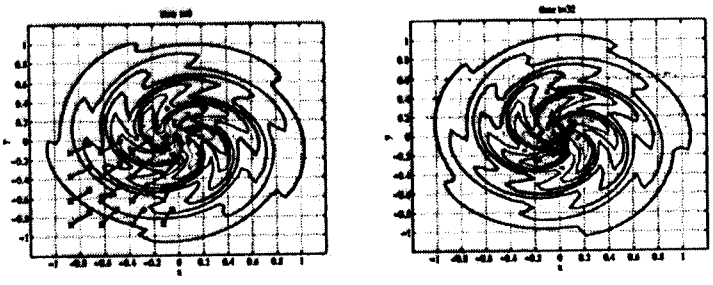
Plume Model 1 Results

- Single and 16 agents
- Single agent fails to find source
- Multiple agents home in



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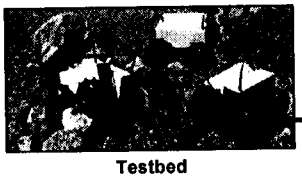
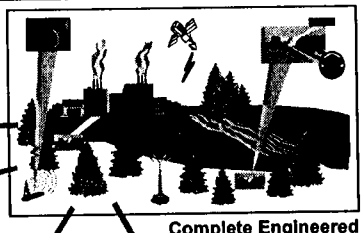
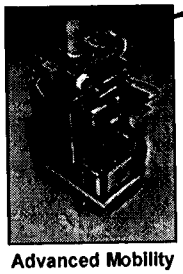
Development of Complete Engineered Collectives



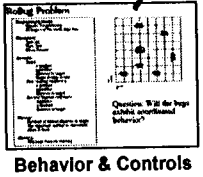
Testbed



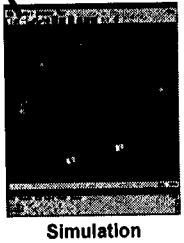
Complete Engineered Collective



Advanced Mobility



Behavior & Controls



Simulation

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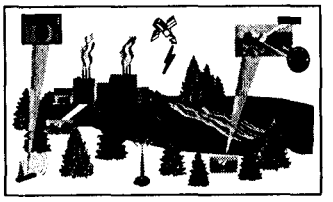
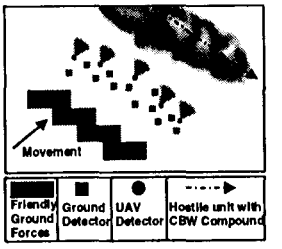
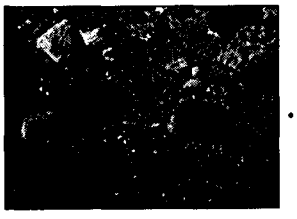
Sandia Strategic Objective: Develop High Impact Responses to Emerging National Security Threats



- **Source Localization** – Small smart machines use cooperation to analyze plumes and locate chemical sources



- **Chem-Bio Weapons Warning** – Distributed vehicles cooperate to form early detection screen with minimal operator interaction



- **Demining** – Cooperative behavior allows vehicles to operate autonomously and to efficiently dispose of mines